2. Physical Environment

Overview

The physical environment determines the extent of the Puget Sound basin and provides the atmospheric and oceanic influences that shape the dynamics of the ecosystem. The physical environment also includes the patterns and processes that create the basic habitat for all organisms. From an ecosystem perspective, the physical environment and the region's biological resources form a single interacting system.

A wealth of ecological literature characterizes the effects of organisms on their immediate environment, and scientific opinion increasingly agrees about human effects at the global scale. For example, in 2001, the Intergovernmental Panel on Climate Change (IPCC) stated that "most of the observed warming [of the atmosphere] over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001). Closer to home, a modeling analysis of potential impacts of global climate change suggests that by 2050 the Pacific Northwest will experience greater annual precipitation but with greater seasonality (Mote et al. 1999). These studies emphasize the interaction between the physical environment and living organisms at a range of scales.

This chapter highlights climatic patterns, streamflows and monitoring results from fresh and marine waters from the last two years in the Puget Sound basin. It also addresses two important components of aquatic habitat in the basin: physical changes to the marine shoreline resulting from development, and disconnection of upper watershed fish habitat from lower freshwater and marine habitats due to fish-barrier culverts. Specific highlights from this chapter include:

- The region experienced the second worst drought on record in late 2000 and early 2001.
- La Niña conditions were interspersed with neutral conditions with respect to the El Niño-Southern Oscillation (ENSO) over the Pacific Ocean. Based on previous return intervals and ocean conditions in early 2002, scientists anticipate that El Niño conditions may emerge in 2002 and 2003.
- The Washington State Department of Ecology developed a new water quality index for rivers and streams designed to measure general watershed conditions. The index shows generally good conditions throughout the basin with fair conditions in south Sound and the lower Stillaguamish and poor conditions at three stations in Skagit County.
- Department of Ecology scientists have developed a ranking of marine water quality concern based on five variables. In this ranking, Budd Inlet, south Hood Canal and Penn Cove showed the poorest water quality but for differing reasons.
- Scientists with the Washington State Department of Natural Resources have determined that 33 percent of Puget Sound shorelines have been modified with bulkheads and half of this amount is associated with single family residences.

El Niño, La Niña and the Southern Oscillation

El Niño and La Niña refer to large-scale perturbations in the pattern of surface temperature in the equatorial Pacific Ocean. El Niño is a warming of the central and eastern equatorial Pacific and La Niña is an anomalous cooling of this area. El Niño events typically persist from 6 to 18 months and recur every 2 to 7 years. They are associated with profound perturbations on weather patterns in many areas of the world.

El Niño typically brings warmer than normal winter and spring weather to the Pacific Northwest but the impact on rainfall is less predictable. The last major event occurred in 1997-98 (see Figure 2-1).

The oceans and atmosphere are part of a coupled system, and as the equatorial Pacific Ocean experiences these large-scale patterns in surface temperature, the overlying atmosphere experiences similarly large-scale oscillations in surface pressure known as the Southern Oscillation. The Southern Oscillation Index (SOI) is calculated from surface pressure at Tahiti and Darwin, Australia and is used to monitor the state of the **El Niño–Southern Oscillation** (ENSO) system.

Findings

Overview of Ocean and Weather Conditions

During 2000 and 2001, the most significant occurrence in the physical environment of Puget Sound was the second-most extreme drought in the 107-year meteorological record. During much of this period, La Niña conditions persisted in the equatorial Pacific with some temporary weakening during the summer of 2000 and a shift to neutral ENSO conditions in the spring of 2001 (Figure 2-1).

Weather Highlights

During the fall, winter and spring of 1999 through 2000, large-scale patterns over the eastern Pacific continued to be consistent with a moderate to strong La Niña over the tropical Pacific (Figure 2-1). For Western Washington, weather conditions are usually cooler and wetter than normal under these conditions (Werth 2001).

During October 1999 through February 2000, precipitation totals were near normal in all areas of Western Washington but well below the record amounts of this period in 1999 (Figure 2-2). The winter snowpack in the Cascade Mountains was above normal levels by mid-December. La Niña conditions weakened in the summer of 2000 and most of Western Washington experienced below normal temperatures and near normal precipitation. A number of areas were exceptions to this pattern, including the northeast Olympic peninsula and other areas (e.g. SeaTac, see Figure 2-2) that experienced an exceptionally dry summer. It was the second summer in a row when the temperature at SeaTac Airport never exceeded 90 degrees (Werth 2001).

Extremely dry conditions during November 2000 through March 2001 resulted in the second driest rainy season in the last 107 years for the Pacific Northwest. Only the 1976 through 1977 period was drier. Many rivers reached record low streamflow levels and reservoirs were depleted to meet water demand. This drought followed a

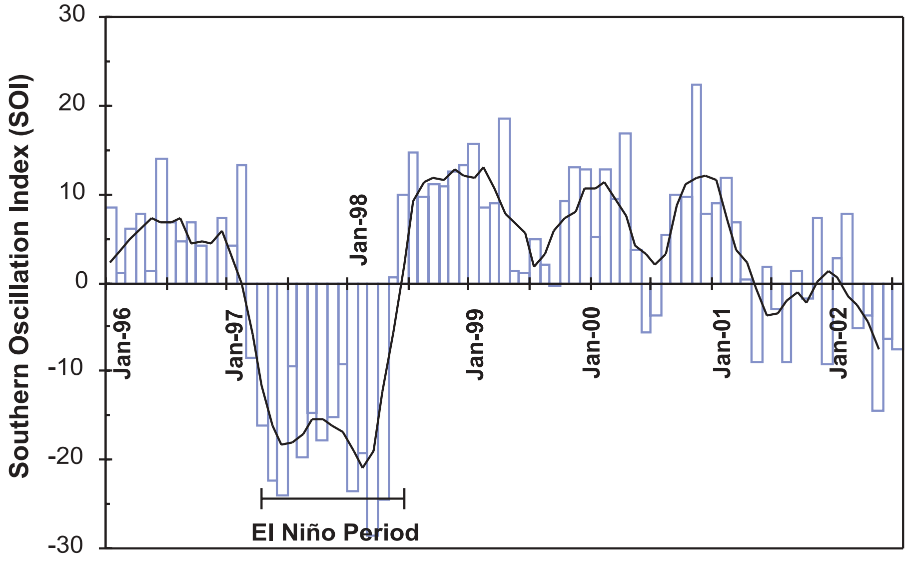


Figure 2-1. Monthly Southern Oscillation Index (SOI) and the 5-month running mean. Persistent negative values are indicative of an El Niño Event.

Data source: Bureau of Meteorology, Australia.

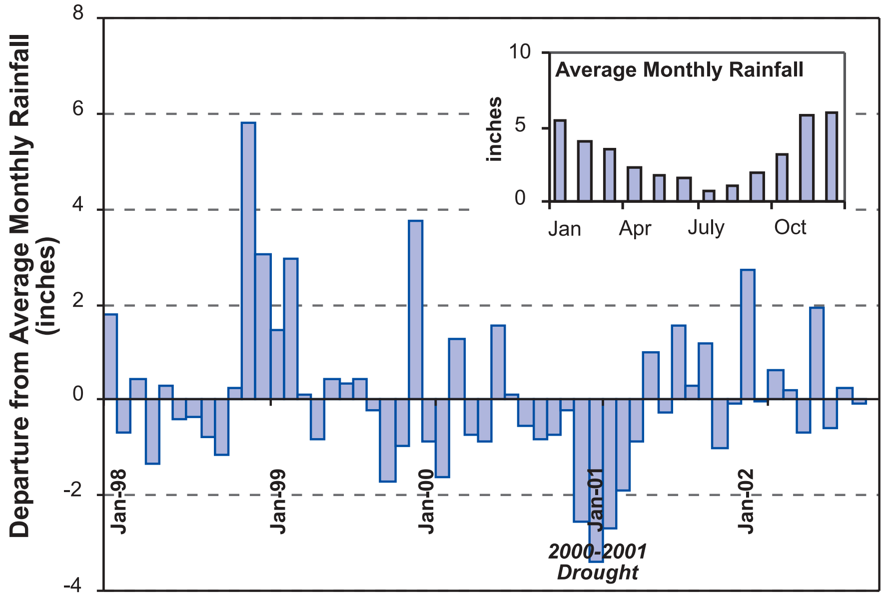


Figure 2-2. Departures of monthly rainfall from average at SeaTac Airport, January 1998 through December 2001. Inset chart shows 30-year monthly mean rainfall.

Data source: National Climatic Data Center (NCDC)

summer that was exceptionally dry in some areas, which resulted in low soil moisture before the onset of the drought. A number of private wells were reported to run dry in the Puget Sound basin. Washington, as well as Oregon and Idaho, declared drought emergencies. A series of Pacific storms near the end of autumn brought a beneficial snowpack to the mountains and a wet start to the 2001-2002 rainy season (NCDC 2001).

Ocean Highlights

The Pacific Ocean influences the physical conditions in Puget Sound directly through exchange of marine waters through the Strait of Juan de Fuca. This exchange is one of the major factors, together with stream water inflow, that control water temperature, salinity and nutrient levels. Upwelling of deeper ocean water is a process that varies over time and has a significant impact on the conditions of coastal ocean water as well as Puget Sound marine water. Upwelled water is cooler, saltier and more nutrient rich than surface water with higher levels of nitrogen, phosphate and silica. The intensity and extent of upwelling influence marine primary production, which affects the productivity and abundance of organisms higher in the food web. Upwelling varies on time scales of days and weeks but can also display patterns over seasonal to interannual periods.

The NOAA Pacific Fisheries Environmental Laboratory (National Marine Fisheries Service) has developed an upwelling index that represents the intensity of upwelling at a number of sites along the Pacific Coast. The index is derived from six hourly and monthly mean surface atmospheric pressure fields. Figure 2-3 shows the recent pattern in the monthly upwelling index for a point off the northwest coast of the Olympic peninsula. The long-term mean pattern shown in Figure 2-3 reflects increased upwelling in the summer months. During 2000 and 2001, no strong periods of suppressed upwelling occurred as in the early months of 1998 and 1999. Increased upwelling did occur in the fall (and late summer of 2001) but well within the level of variation seen in recent years.

Patterns of sea-surface temperature over the Pacific Ocean that change in space and time have also been shown to have important impacts on the Pacific Northwest environment. As noted earlier, El Niño events in the tropical Pacific are linked to climate anomalies in many areas of the world—including the Pacific Northwest—that can affect all components of an ecosystem. A more recent discovery is a pattern in sea-surface temperature in the temperate Pacific Ocean that varies at the scale of decades. This pattern is known as the Pacific Decadal Oscillation (PDO) and has been shown to be closely associated with variations in some fish populations (Hare et al. 1999).

The PDO varies irregularly but is characterized by periods of relative stability that can last for 20 to 30 years with sharp periods of transition, or regime shifts, between these stable states. The index used to track the PDO is based on a multivariate analysis of sea-surface temperatures over the northern Pacific Ocean (Mantua et al. 1997). Statistical analysis of the index time series indicates regime shifts around 1925, 1947 and 1977 (Figure 2-4).

The 1947 and 1977 regime shifts correspond with dramatic shifts in salmon production in the Pacific Northwest and in Alaska. It has been shown that Pacific salmon catches in Alaska have varied inversely with catches from the Pacific Northwest during the past 70 years, and this pattern is associated with the PDO (Hare et al. 1999). For instance, from 1977 to the early 1990s, ocean conditions favored Alaskan salmon stocks and disfavored Pacific Northwest stocks while in the previous period, Alaskan stocks were low and some Northwest stocks were very productive (Hare et al. 1999).

An analysis of western North American tree-ring records shows evidence of the PDO back to AD 1700 (D'Arrigo et al. 2001). It is clear that both the PDO and ENSO are persistent, large-scale oscillations in sea-surface temperature patterns in the Pacific Ocean. It is not clear at this point how the two are related. Mantua et al. (1997) suggest that ENSO operates within the constraints of the PDO, i.e., the PDO regime dictates the amplitude of the ENSO signal.

Rivers and Streams—Freshwater Input to Puget Sound

Freshwater inputs from rivers and streams are an important part of the Puget Sound hydrologic cycle and a major factor controlling the estuarine environment. These inputs have a direct impact on water temperature, salinity and the pattern of these variables both vertically and horizontally within the Sound. Rivers and streams also serve to link the marine environment with the upper watersheds. Human activities in the watersheds affect river nutrient and sediment loadings and the presence of pathogens, which in turn influence the Puget Sound marine environment.

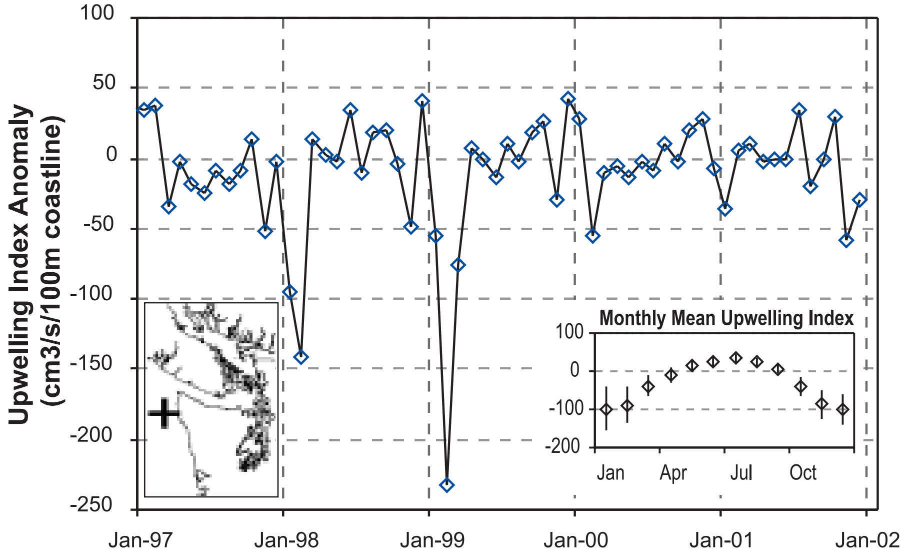


Figure 2-3. Monthly upwelling index anomaly relative to the long-term monthly mean (1967-1991) for the location indicated in the map, 48° North, 125° West. The inset graph shows the long-term monthly mean with error bars indicating +/- one standard deviation. Positive values are associated with increased upwelling.

Data source: NOAA Pacific Fisheries Environmental Laboratory.

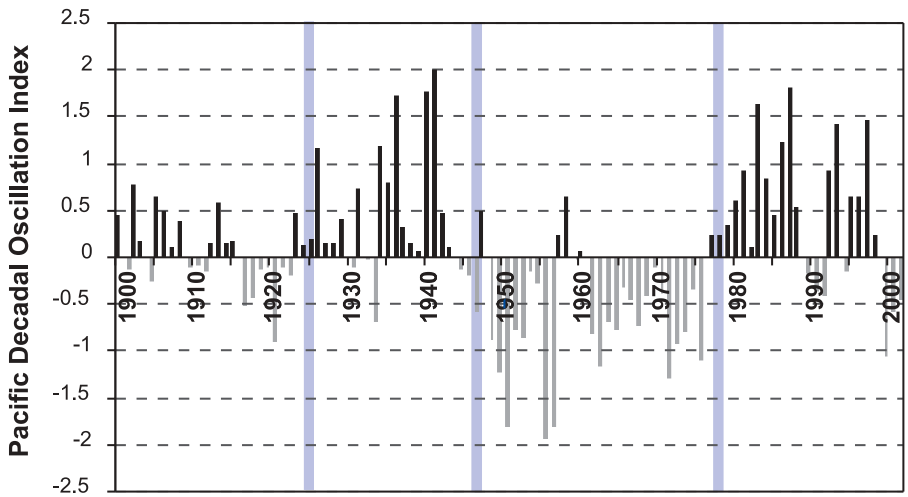


Figure 2-4. Annual Pacific Decadal Oscillation (PDO) index derived from an analysis of sea-surface temperatures over the Pacific Ocean (Mantua et al. 1997). The vertical blue lines indicate regime shifts between different states of the PDO. The data suggest a regime shift may also have occurred in 1998 through 1999, although data from several more years will be necessary to confirm this.

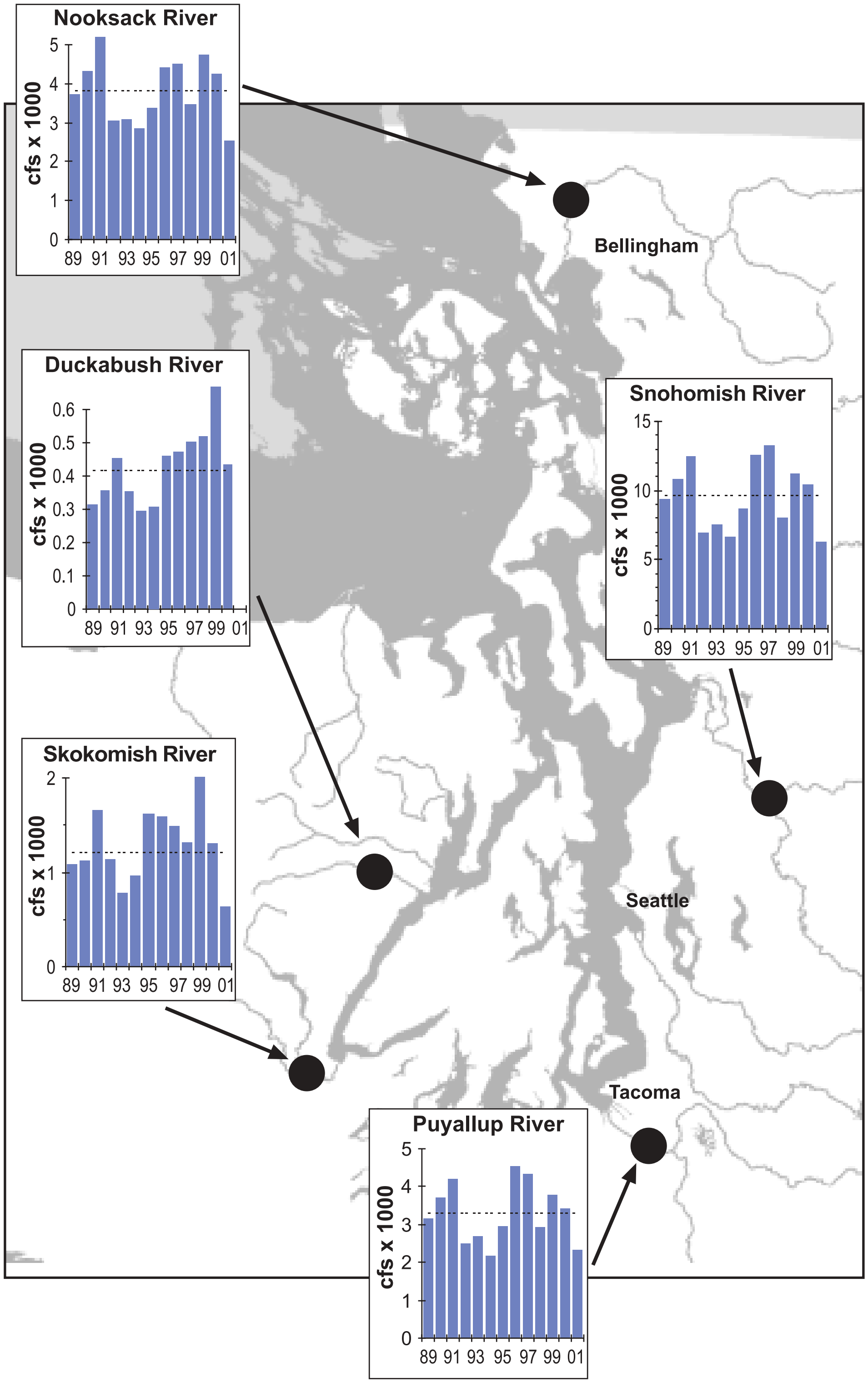
Data source: University of Washington

All streamflow is ultimately derived from precipitation, but it reaches rivers and streams through different mechanisms. Runoff of rainfall is generally the greatest contributor to streamflow but in the spring and particularly in the drier months of summer, snowmelt in the higher elevations becomes a very important source. Groundwater intrusion to stream channels also can be a major contributor to streamflow.

Figure 2-5 shows mean annual flow rate for five major rivers of the Puget Sound basin relative to the long-term averages. These data are calculated on a wateryear basis that runs from October through September of the following year. Wateryear 2001, for example, began October 1, 2000 and ended September 30, 2001. There are local variations in precipitation that are reflected in the different patterns seen in the five rivers over the 13-year record (only 12 years were available for the Duckabush River). Strong climatic signals, however, are generally not localized and these can be seen in data from all the rivers. For example, the 3-year period of below average rainfall from 1992 to 1994 is reflected in all five river flows. Likewise, the recent drought of wateryear 2001 is reflected in data from each river where these data are available. More subtle climatic signals can be seen in the data that are not pervasive over the entire Puget Sound basin but are consistent within smaller geographic areas of the basin. For instance, the three rivers draining the eastern side of Puget Sound (Nooksack, Snohomish and Puyallup) each had above average flows in the years

Figure 2-5. Annual mean flow in five major Puget Sound rivers on a wateryear basis (October through September), expressed as cubic feet per second (cfs) x 1000.

Data Source: U.S. Geological Survey



between 1996 and 2000 and below average flows in 1998. In contrast, the two rivers to the west of Puget Sound that drain parts of the Olympic peninsula had above average flows throughout the 1995 through 2000 period. This reflects the strong geographic patterns that exist within the Puget Sound basin and highlights the importance of understanding basic landscape processes, both physical and biological, at smaller scales.

In addition to the magnitude and timing of freshwater discharge, water quality characteristics of the freshwater inputs are important controlling factors on the Puget Sound marine environment. The Department of Ecology regularly monitors water quality at a number of rivers and streams in the Puget Sound basin as part of the Puget Sound Ambient Monitoring Program (PSAMP). The department initiated its freshwater sampling program in 1970 and currently samples 14 water quality parameters on a monthly basis. The Department of Ecology recently started reporting freshwater conditions using a Water Quality Index (WQI) for eight parameters in addition to a single overall WQI for each sampling station (Ecology 2001). The overall WQI aggregates results from one year of sampling of the eight parameters. These eight parameters include measures of nutrients (total nitrogen, total phosphorus), pathogens (fecal coliform bacteria) and other physical parameters (water temperature, dissolved oxygen, pH, total suspended solids, turbidity) (Butkus et al. 2001). The Department of Ecology also monitors biological conditions (benthic invertebrates) and the spread of invasive, nonnative aquatic plant species.

Figure 2-6 shows the overall WQI analysis for the long-term freshwater monitoring stations in the Puget Sound basin for wateryear 2000. This analysis categorizes just over half of the stations (17 of 33) as being of lowest concern. Some stations in the South Sound area and the lower Stillaguamish were categorized as being of moderate concern. Three stations were of highest concern in Skagit County, two on the Skagit River and one on Joe Leary Slough.

The temperature WQI is shown in Figure 2-7. Temperature is an important parameter influencing habitat quality for a number of aquatic organisms. The results show that there were no chronic water temperature problems at the long-term monitoring stations in wateryear 2000. A trend analysis based on data collected from 1991 through 2000 showed either no detectable trend or decreasing temperatures at all of the monitoring stations (Butkus et al. 2001). These analyses do not imply that there are no temperature problems in the rivers and streams in the Puget Sound basin. In 1998, the Department of Ecology listed 105 fresh water bodies under the federal Clean Water Act—the **303(d) list**—with water quality problems associated with high temperatures. The long-term monitoring stations (Figure 2-7) do not reflect these largely localized problems because the sample design targets sites that are representative of general watershed conditions, e.g., mainstem sampling sites rather than smaller tributaries.

Culverts as Barriers to Migrating Fish

Culverts are pipes or arches made of concrete or metal, that permit water to flow beneath roads where they cross streams. When these streams are bearing fish, culverts are required to be designed to allow for the passage of migrating fish. Many existing culverts, however, present a barrier to fish passage either by improper design, because of changes in watershed hydrology or because of deterioration and the need for maintenance. These culverts may have openings that are too high above the streams for fish to jump into or the culverts may be positioned so that they are too steep. In other cases the culverts are undersized for a particular drainage and may become clogged with debris. These culverts result in habitat loss, as the upstream aquatic areas are made unavailable for spawning and rearing. Fortunately this habitat loss is reversible with maintenance or replacement of these barrier culverts.

The Clean Water Act—303(d) and 305(b) lists

The Washington State Department of Ecology's Water Quality Program uses monitoring data to meet requirements of sections 303(d) and 305(b) of the federal Clean Water Act, pertaining to the status of Washington's water quality. Section 303(d) of the Act requires each state to identify degraded water bodies and submit this list, called the **303(d) list**, to the EPA every two years. The purpose of Section 305(b) is to provide a more general statewide assessment of the state's waters and report the results, called the **305(b) report**, to EPA every two years. In the past, the two reporting requirements were on different timelines. EPA has recently developed guidance for states to merge the two processes, and has set a new transitional deadline of October 2002 to submit both the 303(d) list and the 305(b)report.

When a waterbody is placed on the 303(d) list, the Clean Water Act requires a management effort to restore water quality. This is done through the Total Maximum Daily Load (TMDL) process for individual pollutants. The current list, completed in 1998, was summarized in the *2000 Puget Sound Update.* The Department of Ecology is now in the process of revising the policy guidelines for listing waterbodies that will be reflected in the next 303(d) list.

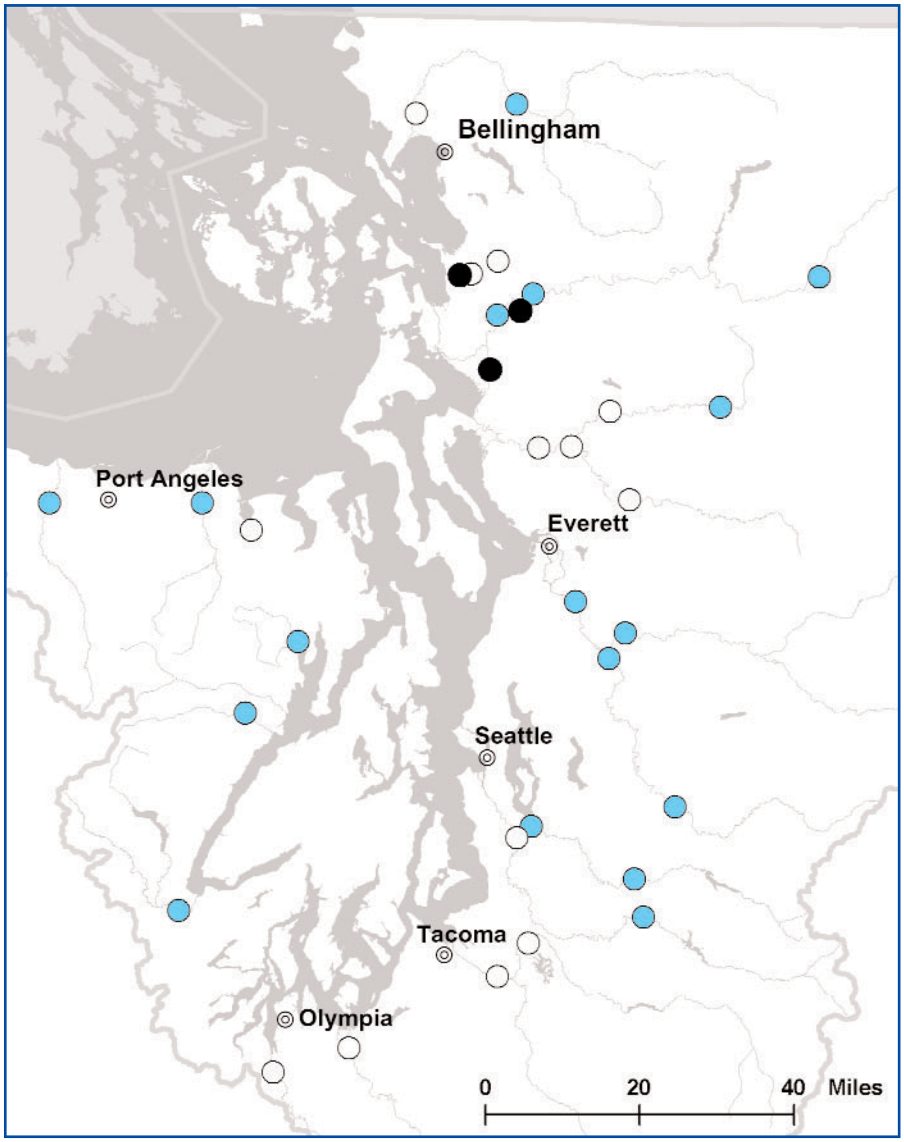


Figure 2-6. Overall water quality in rivers and streams as measured by the Department of Ecology's Water Quality Index for wateryear 2000.

- Highest Concern
- Moderate Concern
- Lowest Concern

Source: Washington State Department of Ecology.

No comprehensive inventory exists of culverts along the 170,000 miles of public and private roads in Washington State (WSDOT 2000). Consequently, the Washington State Department of Transportation (WSDOT) has identified inventory and assessment of culverts as a priority (WSDOT 2000). The Washington State Department of Fish and Wildlife and WSDOT jointly maintain the most complete inventory of culverts. This is the Salmonid Screening, Habitat Enhancement and Restoration (SSHEAR) Fish Passage database. In addition to a simple inventory of culverts, the database includes assessments based on state Department of Fish and Wildlife guidelines, on whether the culverts represent barriers to fish passage. The database also forms part of a broader database that characterizes freshwater and estuary habitat conditions and salmonid stocks in Washington. This is the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP), a joint effort of the Northwest Indian Fisheries Commission and the state Department of Fish and Wildlife. The SSHEAR database is continually improving as new inventories are submitted by tribes, local jurisdictions, state agencies and other entities (Figure 2-8). These new additions to the database include recent as well as older culvert assessments. During 2000 and 2001, several agencies led efforts to expand the SSHEAR database with new culvert assessments: state Department of Fish and Wildlife (934 culvert assessments); Pierce County Conservation District (164 culvert assessments); and Skagit Systems Cooperative (111 culvert assessments). The new

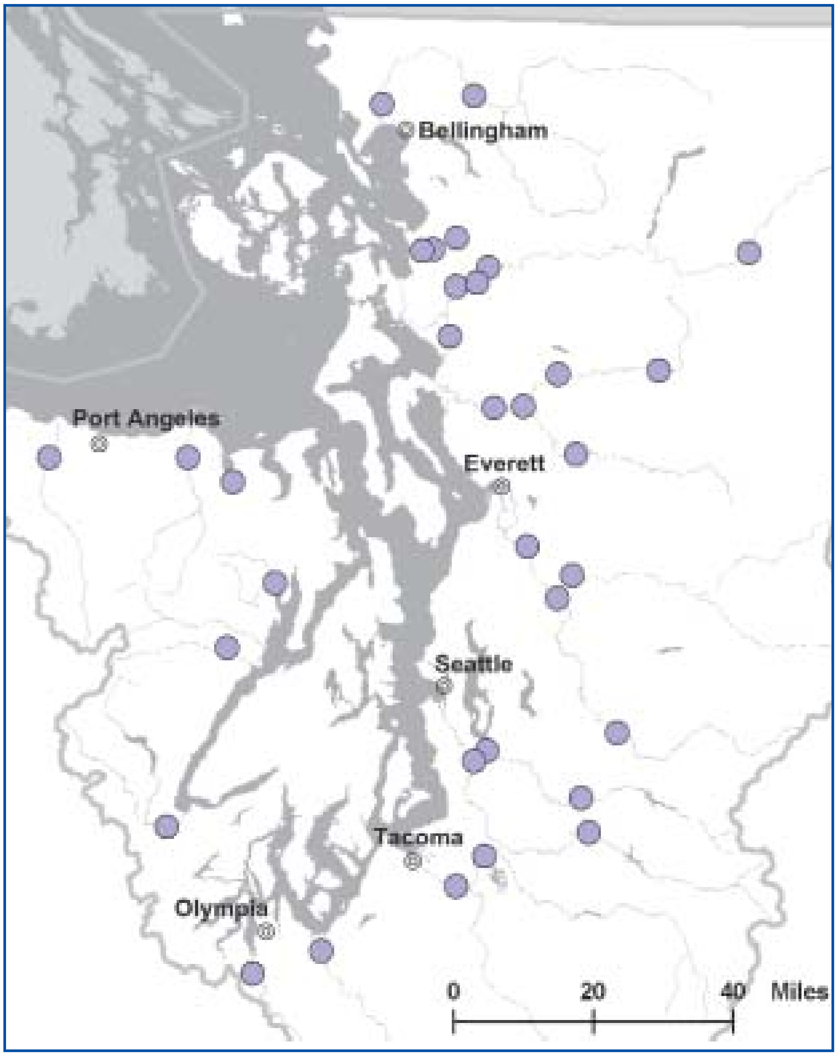


Figure 2-7. Water temperature conditions in rivers and streams as measured by the Department of Ecology's temperature Water Quality Index (WQI) for wateryear 2000.

- Highest Concern
- Moderate Concern
- Lowest Concern

Source: Washington State Department of Ecology.

assessments from Pierce County were primarily in the southern Kitsap peninsula and appear in the Kitsap Water Resources Inventory Area (WRIA) 15 in Figure 2-8.

Currently the SSHEAR inventory contains 4,619 culverts in the Puget Sound basin, but 1,093 of these are located in non fish-bearing streams and therefore do not impact migrating fish. Of the culverts on fish-bearing streams and streams of unknown fish-bearing status, 1,828 (52 percent) have been assessed to be either partial or total fish passage barriers.

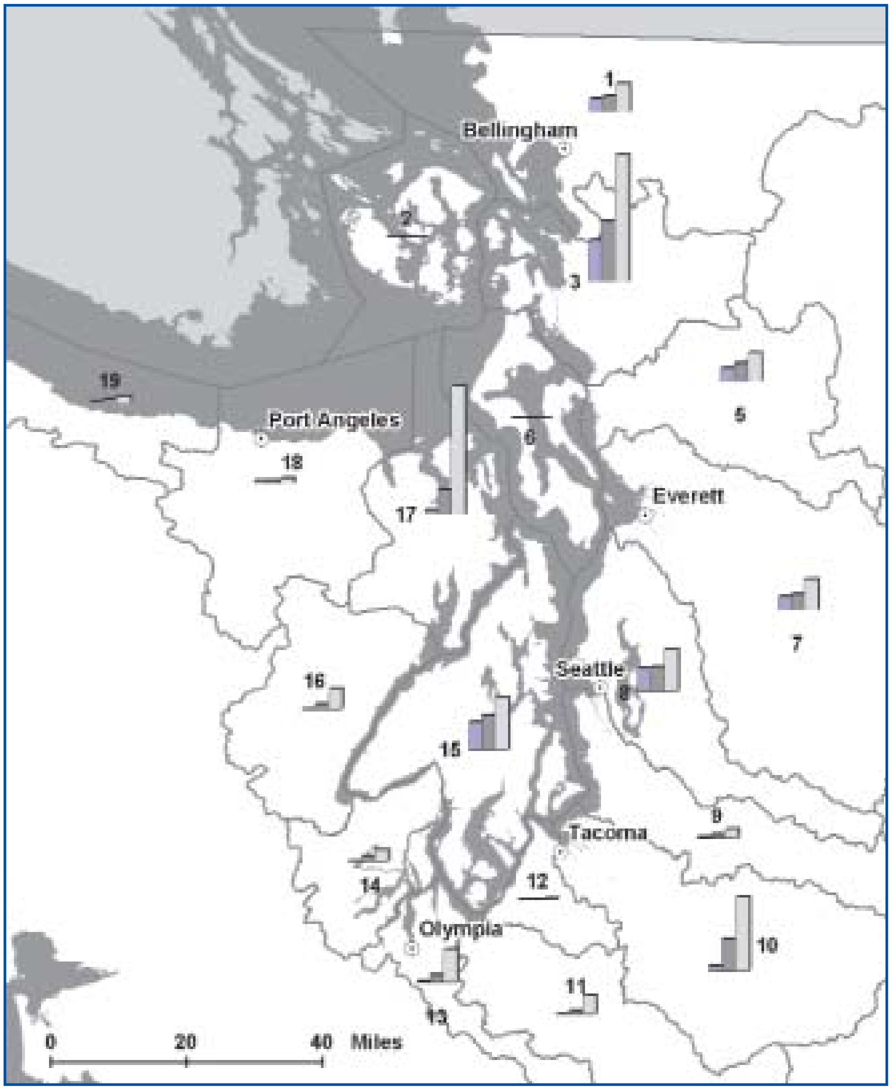
The 2000 and 2001 additions increased the SSHEAR database by 37 percent. This reflects a substantial effort to inventory and assess Washington culverts, but the state Department of Fish and Wildlife estimates that the SSHEAR database represents only 10 to 15 percent of the culverts in Washington State.

Repair or replacement of fish barrier culverts is a priority for protecting salmon populations within the Puget Sound basin. During 1998 through 2000, WSDOT funded the repair or replacement of 84 culverts. During this period many more barriers were eliminated using federal funds, primarily by the U.S. Fish and Wildlife Service through the Jobs in the Woods program (GAO 2001).

Figure 2-8. Culvert inventory for each Puget Sound WRIA as represented in the SSHEAR fish barrier database. The graphs indicate total number of culverts in the database and those that are known fish migration barriers. The number of new culvert assessments indicates the progress made during 2000-01 in reaching a full inventory of Puget Sound culverts.

The Puget Sound basin is composed of Water Resource Inventory Areas (WRIAs) 1-19 as shown.

Data source: Washington State Department of Fish and Wildlife



Culverts on Federal Lands

A recent report by the U.S. General Accounting Office (GAO 2001) reviews the status of culverts and efforts to remove fish passage barriers on federal lands in Washington and Oregon. The report acknowledges that the total number of fish barrier culverts on these federal lands is not known. Based on current assessments, however, federal agencies estimate that restoration of fish passage to barrier culverts may ultimately cost more than $375 million and take decades. Between one to two years is required for each barrier removal project. The Forest Service and the Bureau of Land Management completed 141 culvert projects between July 1998 and August 2001 on federal lands in Washington and Oregon. This effort opened approximately 171 miles of fish habitat to anadromous fish, but most of this was outside the Puget Sound basin.

Puget Sound's Marine Waters

Water properties in Puget Sound are affected by many things, including river flow, air temperature, winds, sunlight and ocean properties. Cold seawater temperatures can either be from an influx of cold, recently upwelled ocean water or from local cool weather. High salinity can be from upwelled ocean water or from a lack of river flow. Department of Ecology scientists are studying how weather and climate influence water properties in Puget Sound.

An important water property for water quality is the degree and persistence of density stratification in the water column. Warm, fresh water is lighter (less dense) than cold, salty water. If there is a strong density gradient, the water column is **stratified.** Whereas if mixing processes, such as tides and winds, disrupt this, then the water column becomes **well-mixed.** The stable layers in a stratified water column are more susceptible to developing water quality problems, e.g. depleted oxygen. For example, the addition of nutrients from human activities to the surface layer of a stratified water column can lead to high nutrient concentrations (since mixing is suppressed) supporting algal blooms. As the algae settles and decays, zones of low oxygen can develop at depth, which can be deleterious to organisms. Thus, stratification has important implications for water quality.

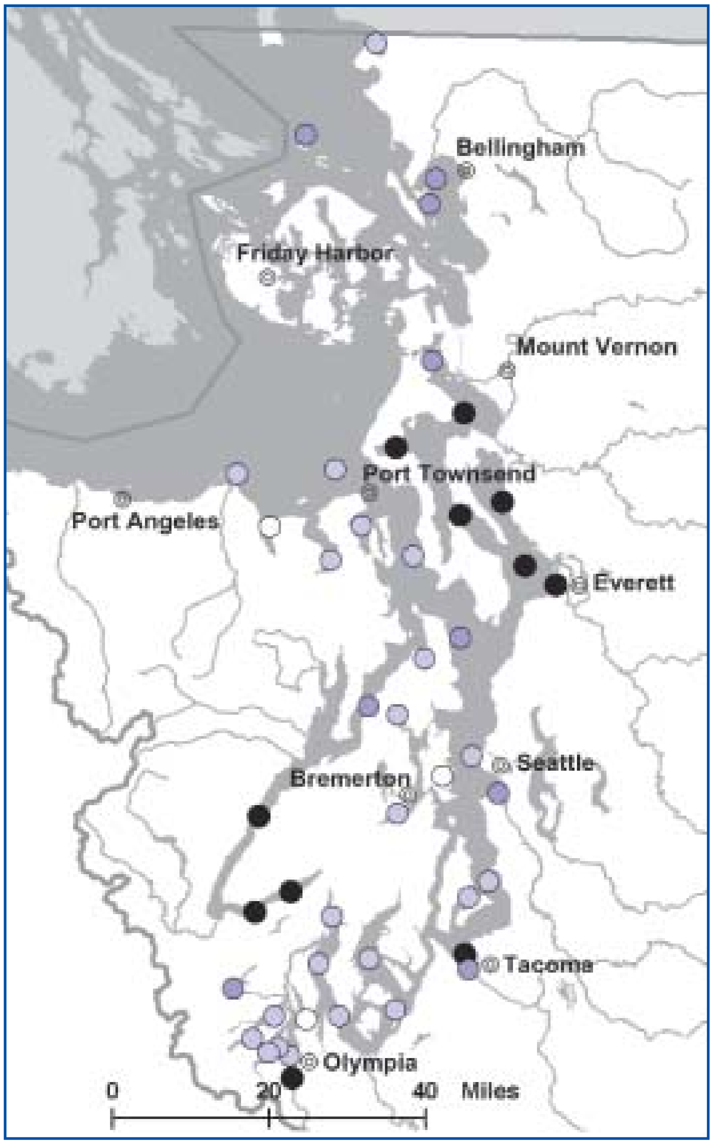


Figure 2-9. Intensity of water column stratification in Puget Sound during wateryears 1998-2000.

Strong and Persistent
Strong and Intermittent
Moderate and Infrequent
Weak and Infrequent

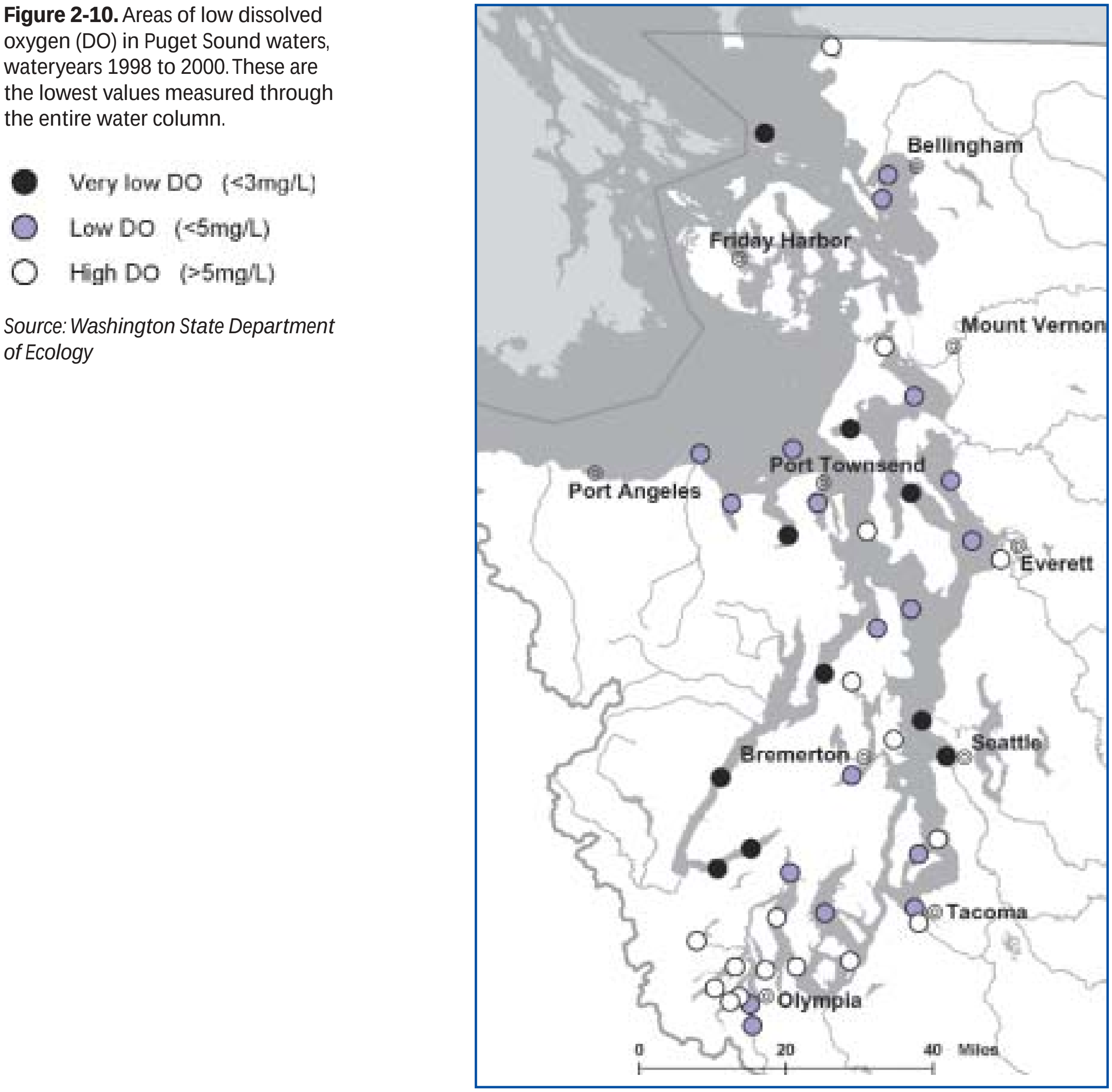
Source: Washington State Department of Ecology

Department of Ecology scientists classify marine water stratification based on both the intensity of the stratification and its persistence. All Puget Sound waters were compared for the strength of density stratification (3 levels) as well as the amount of time it remains stratified (3 levels). Though seven categories were actually possible in the 3x3 analysis, only four were observed in Puget Sound: strong, persistent stratification; strong intermittent stratification; moderate infrequent stratification; and weak infrequent stratification.

The distribution of stratification properties at various monitoring stations throughout Puget Sound is shown in Figure 2-9. As expected, the strongest stratification is found near river drainages.

Figure 2-10 shows locations in Puget Sound where Department of Ecology scientists measured low concentrations of dissolved oxygen from 1998 through 2000. These results represent the minimum dissolved oxygen measured in the entire water column. In the absence of mixing, phytoplankton cells and organic matter will ultimately settle into bottom waters where decomposition of the organic matter consumes dissolved oxygen. In a stratified water column, bottom waters do not circulate to the water surface; therefore, they are not replenished with dissolved oxygen through contact with the atmosphere.

Figure 2-10. Areas of low dissolved oxygen (DO) in Puget Sound waters, wateryears 1998 to 2000. These are the lowest values measured through the entire water column.



Source: Washington State Department of Ecology

While much of the information in Figure 2-10 is similar to that presented previously, there are some differences. In general, dissolved oxygen concentrations seem to be lower in many areas than was found during 1996 and 1997. Observations below 3 milligrams per liter (mg/L) occurred in the Strait of Georgia near Patos Island, Saratoga Passage, north Hood Canal, Elliott Bay, and off West Point, whereas previous observations at these stations were above 3 mg/L. The strong upwelling and shallow thermocline in the Pacific during the 1999 La Niña may have contributed to this signal. Department of Ecology scientists are working to differentiate what part of the signal is from changing ocean conditions and what part, if any, might be due to human effects.

Water Quality Concern

The monitoring of marine waters in PSAMP conducted by the Department of Ecology is focused on assessing temperature, salinity, density, dissolved oxygen, nutrients, chlorophyll, and fecal coliform bacteria. These variables can be used to help assess eutrophication (dissolved oxygen, nutrients, chlorophyll, stratification), sewage waste (fecal coliform, ammonium), food available to secondary producers

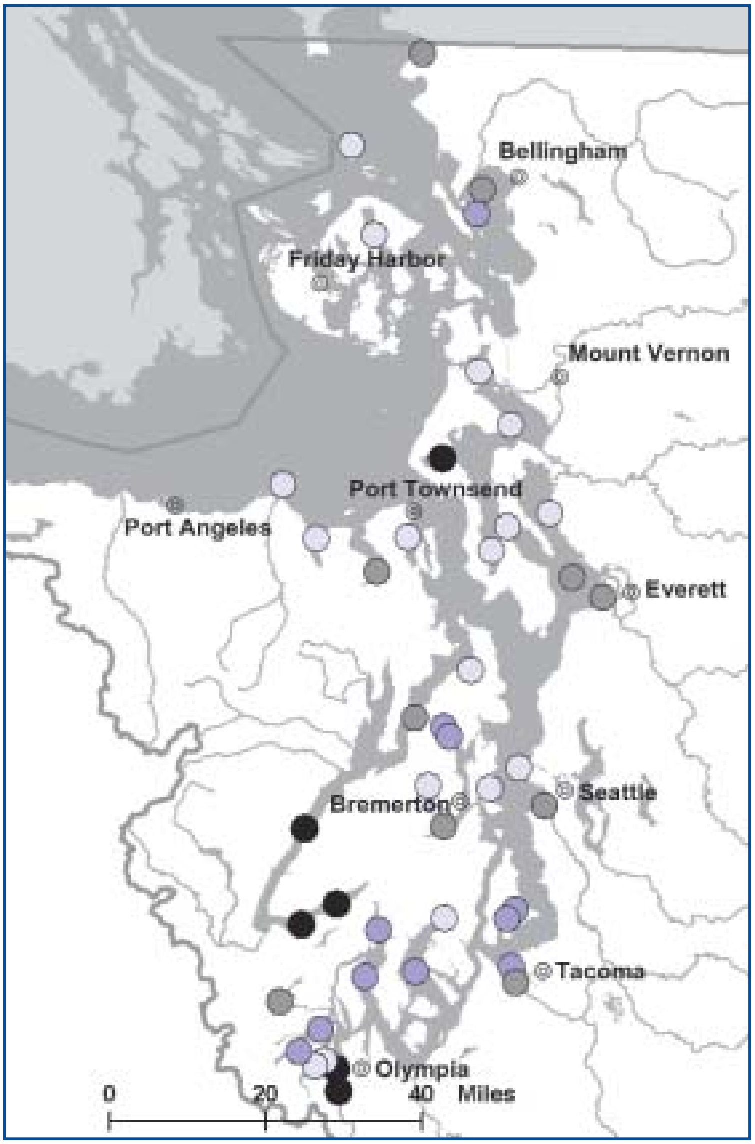


Figure 2-11. Integrated assessment of marine water quality for wateryears 1994-2000. The assessment is based on parameters shown in Table 2-1.

Source: Washington State Department of Ecology

(chlorophyll), and pelagic habitat quality (temperature, salinity), as well as to determine compliance with federal and Washington State water quality standards for temperature, dissolved oxygen, and fecal coliform bacteria. Fecal coliform and nutrient data are presented in more detail in Chapter 3. The determination of water quality concern is based on all these variables and is discussed in this section.

Using these variables, the Department of Ecology scientists have developed five indicators designed to assess overall water quality: strength/persistence of stratification; lack of nitrogenous nutrients for several months; low dissolved oxygen concentrations; high ammonium concentrations; and high fecal coliform bacteria counts. To rank these attributes, the Department of Ecology identified two thresholds for each of the indicators. These indicators are discussed individually in the coming chapters, but collectively these can be viewed to point out general patterns of overall water quality concern.

Figure 2-11 shows the level of water quality concern estimated for various locations in greater Puget Sound using data from 1994 through 2000. Table 2-1 depicts factors responsible for the level of concern. Budd Inlet showed the poorest water quality because it showed high fecal and ammonium concentrations, as well as having strong, persistent stratification with accompanying low oxygen and depleted nutrients. These

Table 2-1. Results for each parameter used to derive the water quality concern index, by waterbody. The indicator attributes of most concern to water quality are shown in blue:

- **DO** = dissolved oxygen
- **FCB** = fecal coliform bacteria
- **DIN** = dissolved inorganic nitrogen
- **NH4** = ammonium
- **Stratif** =stratification

For stratification, results are indicated as:

- **SP** = strong persistent
- **SI** = strong intermittent
- **MI** = moderate infrequent
- **WI** = weak infrequent

Colors in the last column correspond to data in Figure 2-11.

- Highest Concern
- High Concern
- Moderate Concern
- Lower Concern

Source: Washington State Department of Ecology

Station	DO	FCB	DIN	NH4	Stratif	WQ Concern Index
Budd Inlet	**Very Low**	High	**Low**	High	**SP**	
S. Hood Canal	**Very Low**		**Low**		**SP**	
Penn Cove	**Very Low**		**Low**		**SP**	
Upper Willapa Bay		**Very High**	**Low**	Moderate	SI	
Possession Sound	Low	High	Moderate	**High**	**SP**	
Grays Harbor		**Very High**		Moderate	**SP**-MI	
Commencement Bay	Low	**Very High**			**SP**	
Bellingham Bay	Low	Moderate	**Low**	Moderate	SI	
Oakland Bay		**Very High**	Moderate	Moderate	SI	
Sinclair Inlet	Low	High	**Low**	Moderate	MI	
Elliott Bay	Low	**Very High**			SI	
Discovery Bay	**Very Low**		Moderate	Moderate	MI	
N. Hood Canal	Low		**Low**		SI	
Carr Inlet	Low		**Low**	Moderate	MI	
Drayton Harbor		Moderate	**Low**		MI	
Saratoga Passage	Low		Moderate		**SP**	
Case Inlet	Low	Moderate	Moderate	Moderate	MI	
Port Orchard		High		Moderate	MI	
Quartermaster Hbr	Low			Moderate	MI	
Totten Inlet			Moderate	Moderate	MI	
Outer Willapa Bay			**Low**		MI-WI	
Holmes Harbor	Low				**SP**	
Skagit	Low				**SP**	
Port Susan	Low				**SP**	
East Sound	Low			Moderate	MI	
West Point		High			MI	
Dungeness	Low				MI	
Port Gamble	Low				MI	
Sequim Bay	Low				MI-WI	
Dyes Inlet			Moderate		WI	
Eld Inlet			Moderate		MI	
Burley-Minter				Moderate	MI	
Port Townsend	Low				MI	
Strait of Georgia	Low				SI	

waters have received less nutrient input in the late 1990s due to wastewater treatment plant incorporation of nitrogen removal. The bay may be improving, but it is too soon to evaluate with certainty. South Hood Canal continues to have very low dissolved oxygen concentrations and strong nutrient limitation. Oxygen levels appear to be decreasing, though the cause is not easy to evaluate. Other possibilities include eutrophication, changes in circulation due to freshwater diversion, interannual variation, and climate forcing. Penn Cove falls in the highest concern category because of low dissolved oxygen, low dissolved inorganic nitrogen and strong, persistent stratification. The highest fecal contamination is seen in Commencement Bay, Elliott Bay, and Oakland Bay. It is clear from this analysis that water quality is quite varied in Puget Sound and water quality is impaired for a variety of reasons, including natural causes.

More detailed results of dissolved inorganic nitrogen, ammonium and sensitivity to eutrophication are given in Chapter 3.

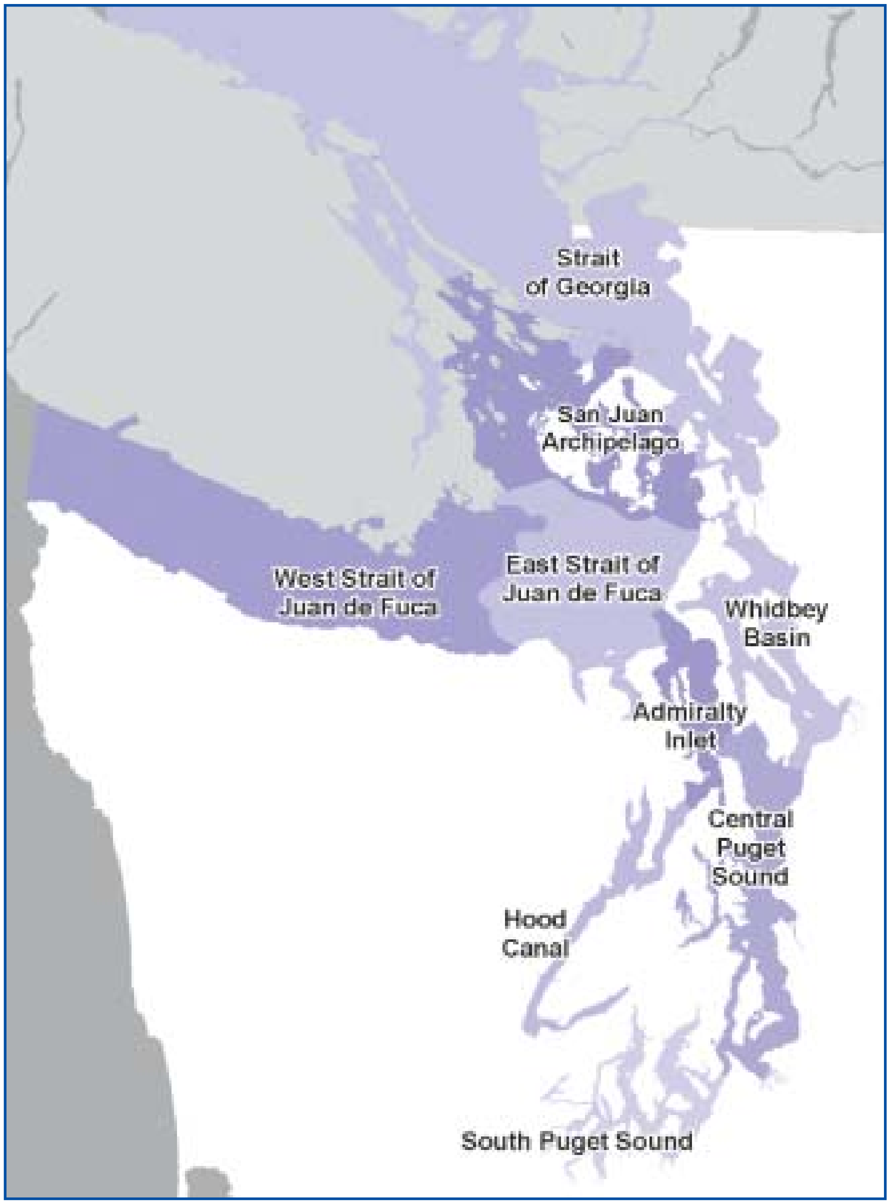


Figure 2-12. Sub-basins delineated by PSAMP. Boundaries largely follow those of Ebbesmeyer et al. (1984).

Source: PSAMP Steering Committee

Delineation of Sub-basins

Puget Sound and the straits of Georgia and Juan de Fuca form a complex network of inland waters. Glacial action scoured several basins, leaving them separated by sills. Denser ocean water enters these basins and circulates at depth while fresher waters from river inputs circulate and move toward the ocean near the surface. Strong mixing and refluxing of water masses occurs at the sills, which form natural boundaries to the basins.

PSAMP has delineated major basins of greater Puget Sound based primarily on the work of Ebbesmeyer et al. (1984) (Figure 2-12). Boundaries coincide with sills where they occur, but some demarcations are arbitrary with no clear physiographic basis. The purpose of this delineation is to provide a basis for common reporting of monitoring results at a sub-basin scale for future editions of *Puget Sound Update* and other reports.

Sills

In Puget Sound sills occur as linear features. They are elevated areas of the bottom of the Sound that partially separate basins. A sill restricts the movement of bottom water masses and can result in partial isolation of the basins.

Puget Sound's Shoreline

Shoreline Modification

Humans have modified Washington State's shorelines extensively. Shoreline modification, such as bulkheads and seawalls, directly converts areas of intertidal habitat to uplands, and indirectly affects habitat through altering nearshore processes. The amount of modified shoreline in an area can be a useful indicator of the extent of human impact on the nearshore environment.

Scientists with the Nearshore Habitat Program at the Department of Natural Resources inventoried the extent of shoreline modification as part of a statewide inventory of saltwater shorelines. The shoreline modification results are discussed here. Other data in the statewide ShoreZone Inventory are discussed in Chapter 6.

The inventory results show that approximately one-third of all saltwater shorelines in Washington State have some of kind shoreline modification structure, such as a bulkhead (Table 2-2).

Shoreline modification is not evenly distributed geographically (Figure 2-13). The outer coast has relatively little modification, while Puget Sound is more extensively modified. The large river deltas in Puget Sound are some of the most extensively modified areas, including the Commencement Bay/Puyallup River areas and the Elliott Bay/Duwamish River areas. These urban embayments were once highly productive estuarine deltas. At the county level, Snohomish County and King County have the most highly modified shorelines. These areas have relatively high population densities and a high proportion of unconsolidated shorelines. Much of the shoreline has been modified (historically and recently) for agricultural, industrial and residential uses. San Juan County has the lowest modification overall. This county is less heavily developed, and many of the shorelines are rocky, which do not tend to erode. In addition to structures such as bulkheads, the ShoreZone Inventory summarizes other types of shoreline modification. For example, it estimates that the state has approximately 1,200 boat ramps, 3,600 piers and docks, and 30,000 recreational boat slips.

Shoreline Modification Associated with Single-Family Residences

Shoreline modifications, such as bulkheads, are known to degrade shoreline habitats by interrupting natural shoreline processes. For this reason, a variety of state and federal statutes regulate shoreline modification projects. State statutes exempt projects associated with single-family residences or subject them to less stringent criteria. In the past, resource managers have suggested that existing policies might be altered to address the cumulative impacts of shoreline modification due to single-family residences. However, the relative proportion of shoreline modification associated with single-family residences was not known.

To determine the relative significance of single-family residences in overall shoreline modification, Department of Natural Resources scientists collected data on the proportion of shoreline modification along state saltwater shorelines associated with single-family residences. They found that approximately half of all shoreline modification in Washington State is associated with single-family residences (55 percent ±9 percent). This finding suggests that shoreline modification associated with single-family residences is a major component of total shoreline modification.

County	Total Miles	Miles Modified	Percent Modified
Snohomish	133	99	75%
King	123	84	68%
Pierce	239	129	54%
Thurston	118	54	46%
Kitsap	254	110	43%
Mason	231	92	40%
Skagit	229	81	35%
Whatcom	147	49	34%
Grays Harbor	187	45	24%
Island	214	49	23%
Pacific	276	57	21%
Clallam	254	27	11%
Jefferson	254	22	9%
San Juan	408	19	5%
Puget Sound	2469	813	33%
Outer coast	598	104	17%
TOTAL	**3067**	**917**	**30%**

Table 2-2. Shoreline modification by county.

Source: Washington State Department of Natural Resources

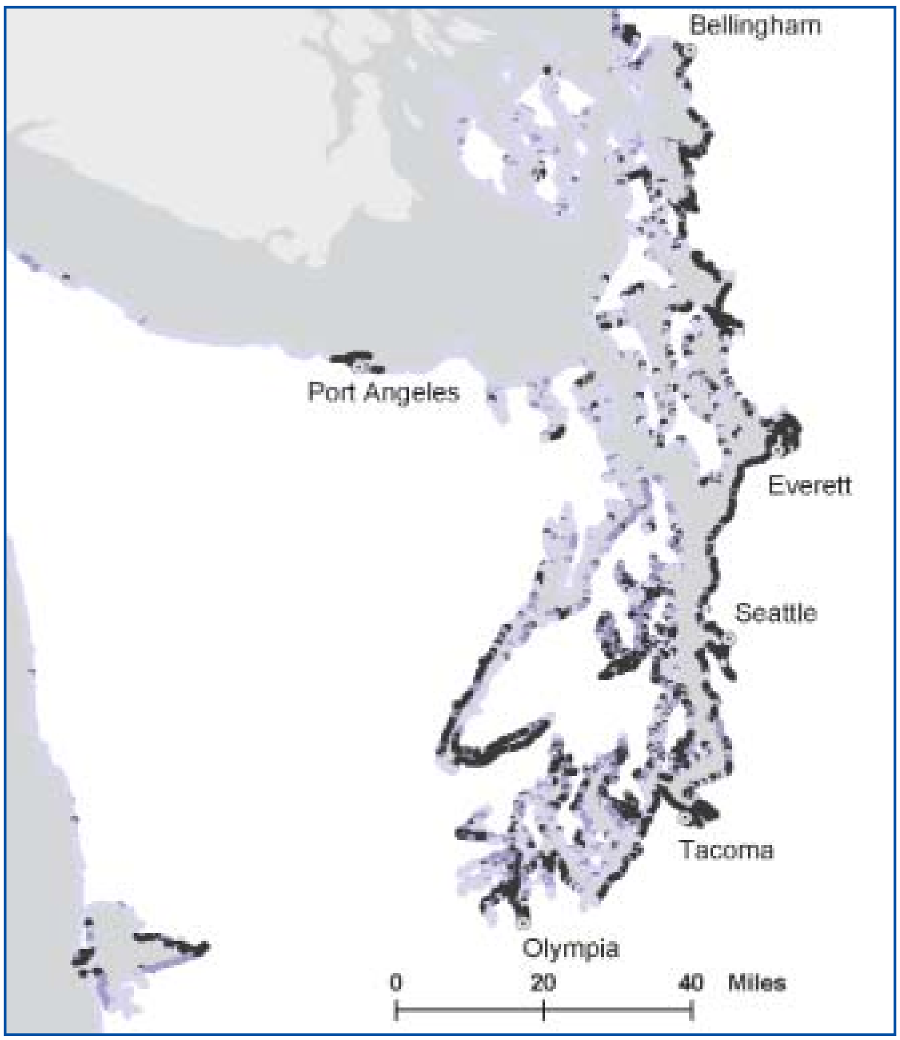
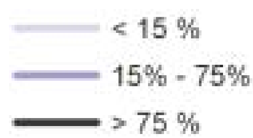


Figure 2-13. Shoreline modification.



Source: Washington State Department of Natural Resources.

Acting on the Findings

The findings presented in this chapter suggest specific actions for the region's resource managers, including:

- Resource managers and planners should investigate opportunities to integrate our developing understanding of climatic cycles into ecosystem-based management of the region's habitats and species.
- Shoreline modification associated with single-family residences is a major component of total shoreline modification. State and local governments should review policies that regulate shoreline modification for single-family residences to ensure patterns of modification are balanced with the protection of Puget Sound.
- Scientists need to better understand the role of groundwater in Puget Sound's freshwater budget.